A Sensor Based Low Cost Drowning Detection System For Human Life Safety

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Abstract: **In this paper, we present an approach which addresses the problem of drowning. Drowning is one of the leading causes of accidental deaths which needs to be given attention. The objective is to address the question-how can we engineer a system that saves the life of a drowning person? The devised system has the capability to automatically detect drowning by making use of three sensors, namely, a non-invasive oxygen saturation level sensor, respiration monitoring sensor and water sensor that are used for detecting parameters like blood oxygen saturation levels, respiratory movements and submersion of a person's body underwater respectively and a controller for monitoring, processing and controlling purposes. If any two of the above mentioned parameters detect drowning, the system detects it as a case of drowning. Results obtained by performing tests on individual sensors and entire system illustrate the effectiveness of the approach. Thus the approach is a viable solution to devise an innovative, portable, low cost and wearable system.**

Keywords: **Embedded system, wearable, drowning detection, respiratory monitoring sensor, oxygen saturation level detector, body parameters.**

I. INTRODUCTION

Drowning is a form of asphyxia due to aspiration of fluid into air passages, caused by submersion in water or other fluid [1]. Globally, drowning is one of the major causes of accidental deaths. As of November 2014, drowning mortality rate was 1.3 – 3.9 per 100000 in most parts of South America and North America [2]. The situation is even worse in Russia which had a drowning mortality rate of more than 3.9 per 100000 [3]. In India too, drowning accounts for the second largest cause of accidental deaths, for children below 15 years of age [3]. The above statistics reflect the need for focusing our attention on this critical topic which has been neglected for long, and hence, it was decided to develop a system which can provide a reference for future developments.

II. LITERATURE SURVEY

In the recent past, various technologies have been developed to increase aquatic safety for humans. These technologies range over a wide spectrum from simpler techniques which only detect if a non-swimmer has fallen into water, to more complex automatic video surveillance methods. The method proposed in [4] comprises a portable transmitter attached to the body of a non-swimmer, which is actuated when the non-swimmer falls into water, wherein, the actuating means comprises of two electrodes adapted to be electrically bridged by the electrical conductivity of water; the transmitter sends a signal to trigger an alarm outside the water. This method can be used to detect if a non-swimmer (infant) has fallen into water, but cannot distinguish a person who is drowning from one who isn't. A method has been proposed in [5] which monitors the absence of motionless bodies at the bottom of the pool by making use of underwater cameras. Most camera based methods are more or less an improvement on this method. Similarly, an approach mentioned in [6] uses an active sonar system to scan the surface within the volume of the pool to generate images from which the system can discern objects and humans who are stationary. However, the above two methods are accompanied by high costs to set up underwater cameras and also face complex underwater installation and housing problems. To add to these, the underwater cameras also face the issue of blind spots. To counter a few of the drawbacks associated with underwater cameras and networks, various techniques which monitor the swimming pools by making use of overhead cameras have been developed and discussed in [7] [8], but they too have to deal with various air water interface issues associated with refraction, water quality, glare on the water surface and many more. The earlier approaches mentioned in [5] – [8] are also subject to very high costs and have a fixed and restricted area of operation due to the lack of portability. The devised system, however, is portable, less costly, wearable and person independent.

In order to achieve the above advantages, it was imperative to develop a system based on certain body parameters. Usually, the process of drowning takes 3-4 minutes and is marked by inevitable entry of water into the mouth resulting in vigorous coughing, loss in corneal reflex, increase in blood volume, gradual decrease in blood oxygen saturation level and change in electrolytes [1]. After consulting a number of doctors having various specializations, two body parameters were selected i.e. blood oxygen saturation level and movement of the chest when a person coughs. To add more robustness, a third parameter was selected which detects if a person is submerged underwater.

III. SYSTEM BLOCK DIAGRAM AND DESCRIPTION

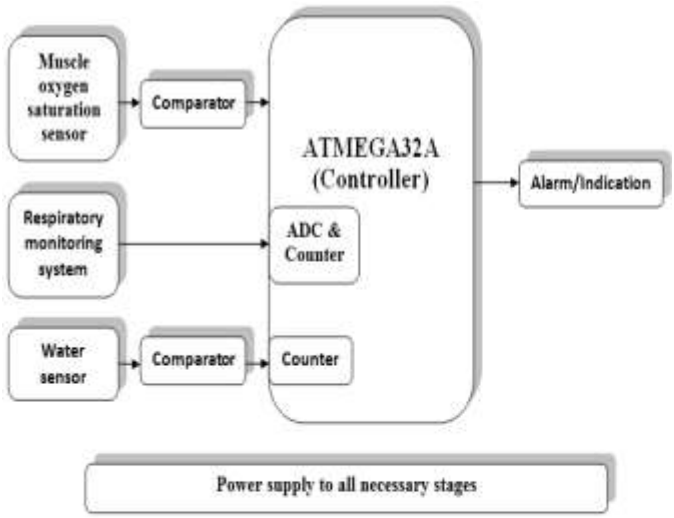

Fig. 1. Block Diagram of the system.

As per the parameters selected, the designed system, shown in Fig. 1, consists of sensors which will be continuously monitored by the controller and will alert the surroundings by using an alarm/indication.

The sub units are as follows:

1) Water sensor
2) Respiratory Monitoring System (RMS)
3) Muscle Oxygen Saturation Sensor (MOSS)
4) Controller
5) Power Supply
6) Alarm/Indication

Following sub sections describe the working, construction and corresponding tests for each sub unit.

A. Water sensor

Introduction: This sensor helps to distinguish between three cases, they being, a person normally swimming, the person being outside water and the person who is drowning. The sensor is expected to be placed on the forehead and cheeks as complete submergence of these can aid to detect submergence of person under water. Also, it detects the first time the person enters water, upon which, the processing of the system starts or else the system stays in standby state. This allows the system to limit its power consumption and makes it more reliable and immune to faults.

Construction: As it can be seen in Fig. 2, the sensor is composed of two exposed traces. These two traces are interlaced with each other and are called ground trace and sense trace. The ground trace is connected to ground whereas the sense trace is connected to a resistor so that it pulls up its value when it comes in contact with water.

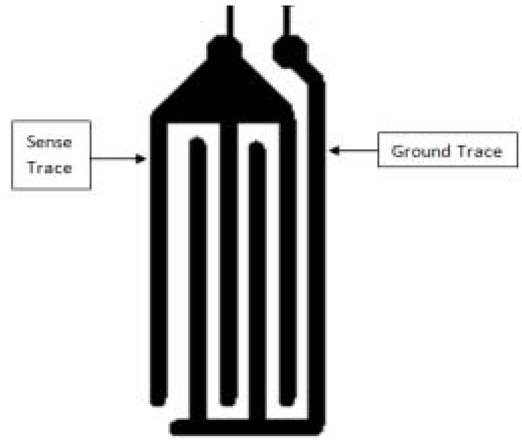

Fig. 2. Water Sensor Construction

Working Principle: This sensor determines if the person is in contact with water or not by using the property of conductivity of water. When water comes in contact with the sensor, the two traces are shorted which gives a corresponding analog volatge.

Signal conditioning: The sensor is interfaced to the microcontroller using a comparator. The comparator is set with a reference value. Hence a corresponding high voltage value denotes that a person is under water and a low voltage value denotes that the person is out of water.

Tests and Results: Tests were carried out to check the response of the sensor in various conditions, for instance, wide temperature ranges and different qualities of water. These results verified the functionality of the sensor.

B. Respiration Monitoring Sensor (RMS)

Introduction: When a person begins to drown, a lack of oxygen or an urge to call out for help results in water entering the person's mouth that forces its way to the larynx resulting in frequent and vigorous coughing [1]. This aberrant respiratory pattern resulting from vigorous coughing can be used as one of the measures to identify if the person is drowning.

Construction: RMS comprises of a piezo disc which is fastened on the person's chest /abdomen using a piece of elastic and an inflexible belt as shown in the Fig. 3. Also, a knob is constructed on the piezo disc to easily transmit the force from the chest/abdomen to the piezo disc [9].

Working Principle: When the person's chest/abdomen expands it exerts a force on the piezo disc that generates a proportional voltage in accordance with the expansion. A larger expansion generates a voltage in the higher range and a compression (smaller expansion) generates a voltage in the lower range.

Signal conditioning: This analog signal obtained from the piezo disc is then passed on to the Analog to Digital Converter (ADC) of the controller, to digitize it for processing.

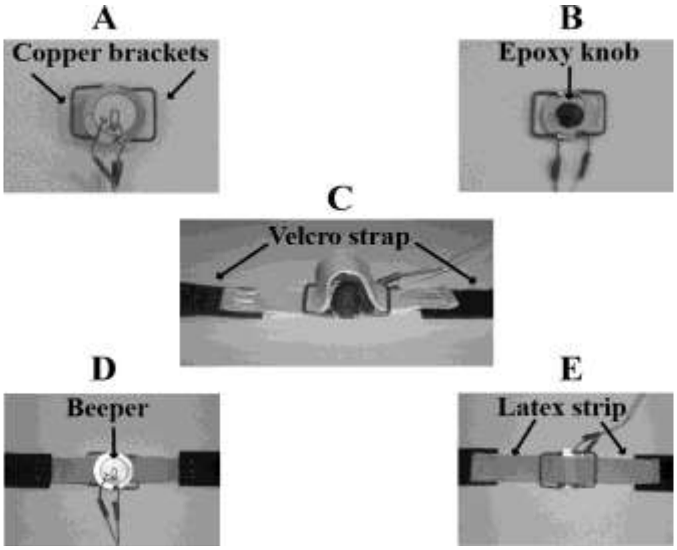

Fig. 3. Construction of RMS Sensor.

Tests and Results: After carrying out various tests a sufficiently large sample set was obtained from which a threshold was inferred. This threshold value was used to detect the aberrant respiratory pattern on the basis of output voltage levels. The number of times this aberrant pattern occurs in a given time duration was also recorded.

C. Muscle Oxygen Saturation Sensor (MOSS):

Introduction: For measuring blood oxygen saturation, generally Pulse oximeter is used. This device which is strictly attached to finger allows the light to pass through it and the non absorbed light is received which generates the required output [10]. Whereas, MOSS, which can be attached to the arm or thigh allows the light to travel through skin and the reflected light is received to generate the output. As the person starts drowning, the blood oxygen saturation gradually decreases. Normal range of oxygen saturation is 95-100 % [1]. MOSS, which is a non invasive device, measures oxygen saturation in muscle tissue, which is the percentage of hemoglobin molecules carrying oxygen. Oxygenated and deoxygenated hemoglobin molecules are chromophores which are groups of atoms within a molecule that absorb light differently at different wavelengths [11]. It is possible to measure concentration of chromophores using Beer Lambert's Law [11].

Construction: A suitable pair of a near Infra Red (IR) Light Emitting Diode (LED) and a photodiode is used for transmitting and receiving light. MOSS consists of three IR LED's connected in series and two photodiodes in parallel, with a small specific distance between them. All the optodes are placed in straight line as shown in the Fig. 4.

Working Principle: This sensor is attached to the arm in such a way that all the optodes are facing the skin of the arm. The light transmitted from near IR LED travels through skin, fat and reaches the muscle tissue. The transmitted light is absorbed depending upon the number of hemoglobin molecules present (using Beer Lambert's Law) and remaining light is reflected back which is captured by photodiodes producing the output accordingly.

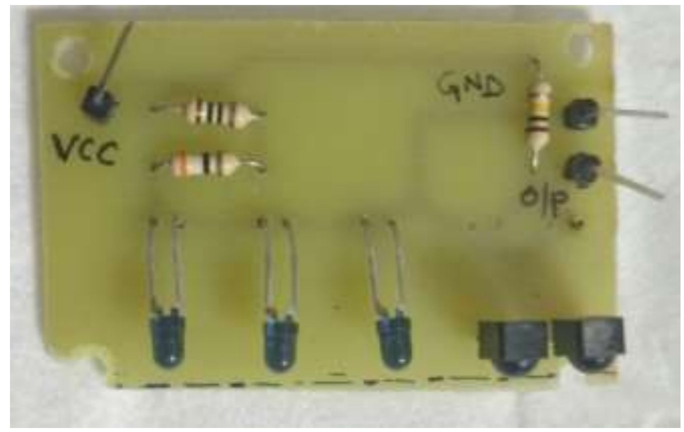

Fig. 4. Construction of MOSS.

Signal conditioning: Using pulse oximeter [10] as a reference, oxygen saturation percentage is mapped with MOSS voltage output. This voltage is given to a comparator and threshold for comparator is kept such that- for normal oxygen level- comparator output is high and for low oxygen level- comparator output is low.

Tests and results: Various tests were performed on people with normal oxygen levels and patients having low oxygen levels and observed readings were verified with expected results. These results were also used to decide the number of LEDs, photodiodes and inter-optode distance between them in order to achieve more accurate results.

D. Miscellaneous

The ATMEGA 32A controller is used which has inbuilt ADC and timers. The microcontroller receives the output from each sensor and continuously processes the received data to check the condition of drowning. Batteries are used to provide power to the all required devices making the system portable. Drowning is indicated by using alarm.

IV. WORKING

The above mentioned three sensors are monitored continuously by the controller. The controller then works on the data received continuously and detects if the person is drowning with the assistance of the devised algorithm. The devised system is a wearable one and has to be put on just like clothes. The person needs to switch it on only the first time he/she wears it.

1) Now, before the person enters water (either willingly or accidentally) the sensor data will be received by the controller, but the part of processing which comprises of checking if the person is drowning will not be carried out until the person enters water for the first time. All steps and further processing mentioned occurs only if this condition is fulfilled.

2) The essence of the working of this system lies in incorporating a time cycle. The duration of this cycle is 'x' seconds (where x is the approximate time duration for which an average person can remain completely submerged under water with manageable impediment.). All the processing is carried out in this cycle of 'x' seconds and this cycle is repeated continuously, one after the other, till the time the system is switched off as shown in the figure 5. Hence, describing the entire system processing would ultimately come down to describing a single cycle processing.

3) Three sensors are employed to increase the reliability of the system. All the three sensors work independently and all of them have their own individual conditions to detect drowning. These conditions are checked by the controller on the basis of the algorithm. If the condition of a specific sensor is met it individually detects a case of drowning. If any two of the three sensors (or all three sensors), detect a case of drowning independently, only then the system indicates drowning.

4) The MOSS sensor output received at the controller after signal conditioning is either a logic high or logic low. High logic level indicates that the blood oxygen saturation level is within an innocuous range. However, logic low indicates that the oxygen saturation level has dropped quite low and may prove unsafe. The blood oxygen saturation level decreases gradually and slowly. It is a critical parameter, and hence the system is designed in such a way that is detected as soon as it enters the unsafe range. If the blood oxygen saturation level enters the unsafe range, it is detected as a case of drowning by this sensor individually. During the entire cycle, monitoring and checking is carried out continuously.

5) The RMS sensor output received at the controller is an analog voltage signal that is digitized using the controller's ADC. The controller monitors two basic things, namely ,monitoring if an aberrant pattern is obtained using the voltage levels and monitoring the number of times this aberrant pattern is obtained in the duration of a cycle (i.e. 'x' seconds). If the number of times the aberrant pattern occurs in one cycle is more than a predefined threshold, it is detected as a case of drowning by this sensor. During the entire cycle, monitoring is carried out continuously, but checking if the number of times the aberrant pattern exceeds the threshold is carried out at the end of every cycle(i.e. at the end of every 'x' seconds)

6) The water sensor output received at the controller after signal conditioning is either logic high or logic low. High logic level indicates that the person (person's cheeks and forehead) is under water at that instant and a low logic level indicates that the person is above water at that instant. The algorithm is such that if there is no high to low transition in one cycle (i.e. 'x' seconds) then it indicates that the person has remained under water for more than one cycle duration (i.e. for more than 'x' seconds), and that it could be unsafe for him to remain under water for longer. Hence, this is detected as a case of drowning by the water sensor. During the entire cycle, monitoring is carried out continuously, but the transition occurrence can only be checked at the end of the cycle.

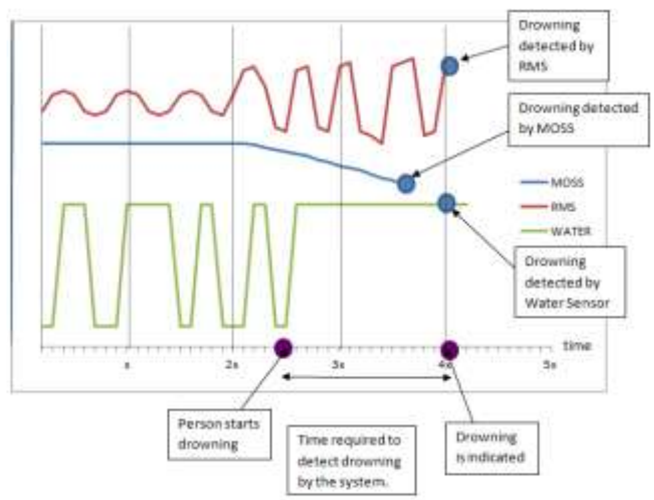

Fig. 5. Timing Diagram

7) An illustration of how the system works has been described by using a timing diagram as shown in Fig.5. The diagram shows the outputs of the various sensors. Also, a random point is chosen (for the purpose of generality) to indicate when the person starts drowning. Furthermore, time instants at which the sensors independently detect drowning are also shown. MOSS is shown to detect a case of drowning the earliest (immediately after threshold is crossed), whereas the other two detect it at the end of the next cycle. As the condition for drowning is fulfilled at the end of the fourth cycle, drowning is indicated by the system.(Note that this is not always the order in which the sensors detect. It may differ from situation to situation)

8) Time taken for detection by each sensor individually after their conditions have been fulfilled can be summarized as follows:

TABLE I: TIME REQUIRED TO DETECT DROWNING

Sensor	Minimum Time (in seconds)	Maximum Time(in seconds)
MOSS	0	0
RMS	0	x
Water sensor	x(x)	2x
DDS	0	2x

V. TEST CASE IMPLEMENTATION AND DISCUSSION

A. Water Sensor

In order to verify the functionality and response time of the sensor, tests were carried out by dipping the sensor in and out of the water and changes in voltage values were recorded. Based on these readings, a reference voltage was set for the comparator and changes in its output voltage on crossing the reference value were verified. Also, detection of case of drowning by water sensor when the sensor is under water for more than ‘x’ seconds was tested and verified. Tests were also carried out to check if the system starts only when the person enters water for the first time.

B. Respiratory Monitoring Sensor

Preliminary tests were carried out to understand the difference between the respiratory patterns obtained when a person is breathing normally, breathing heavily and coughing vigorously. On the basis of this, tests involving signal conditioning using an ADC were carried out and a threshold for voltage levels of aberrant pattern and a count for the number of times the pattern occurs in a cycle were decided and results were verified. Also, tests were carried out successfully to check if the case of drowning is detected independently by this sensor.

C. Muscle Oxygen Saturation Sensor

Tests were performed on two sets of people, patients (from a reputed government hospital) with low oxygen saturation levels and people with normal (or high) oxygen saturation levels.

MOSS and pulse oximeter (used as a reference) were simultaneously used. The MOSS output voltage values were then mapped to the corresponding pulse oximeter output to obtain Table II. An appreciable difference in the voltage values for people with oxygen saturation levels in innocuous range and unsafe range were observed, which was then used to set a threshold for a comparator. Also, tests for checking if a case of drowning is detected by this sensor independently were carried out successfully.

TABLE II: Mapping of Oxygen Saturation Percentage to Voltage

No.	Samples	Gender	Age (Years)	Oxygen saturation (%)	Voltage (V)
1	Person 1	Male	16	95	1.27
2	Person 2	Male	41	94	1.10
3	Person 3	Female	32	92	0.85
4	Person 4	Female	46	90	0.53
5	Person 5	Male	58	87	0.35
6	Person 6	Female	53	85	5.02

Fig. 8 Voltage output for person having low oxygen level

D. Complete System

Integration of all the sensors and other sub units was done and following test was conducted and verified - The system detects a case of drowning if and only if two or more sensors independently detect it as a case of drowning.

VI. CONCLUSION

In this paper, we have presented an approach to devise a system which detects drowning. All the sensors were designed as per the requirements. Numerous tests were carried out to check the functionality of each sensor and the obtained results were satisfactory. Based on the amount of time each individual sensor requires to indicate drowning, we calculated the approximate time required for the system to detect drowning. We designed our system in a way that drowning is detected only when it is indicated by any two of the three sensors (or all three sensor) making the system robust and enhancing its performance. The system can further be improved by incorporating wireless technologies making it more compact. Experimental results show that we have established a prototype system which is robust and beyond the stage of proof-of-concept. The proposed approach can be viewed as a reference for future work in this area.

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FUTURE SCOPE

Currently the system has the capability to be introduced as a product; however, its capabilities (functionality) can be enhanced by making a few improvements. In past, a lot of work has been done in the field of underwater communications. For instance, the idea proposed in [12] is concerned with a portable device like a watch consisting of microprocessor and a sound generator that can be worn by a diver which communicates with other divers and a person outside water by emitting alarm signal using sound generator. The technique presented in [13] comprises of a signal or alarm generating device which is activated if predefined condition occurs and informs a receiver mounted outside the water. Similar technique can be incorporated in our system that will communicate with nearby people by sending alarming signal when drowning is detected.

Perhaps the best improvement that can be made to the system is the ability to inflate a small bag through a portable cylinder. This addition makes the system save the person along with alerting the people in the surroundings.

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